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CONTRIBUTION OF THE SUPPORT LEG TO ACCELERATE KICKING LEG SWING DURING SOCCER INSTEP KICKING

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The present study aimed to determine the contribution of support leg motion to the acceleration of the kicking leg in soccer instep kicking. The kicking motion was recorded by a motion capture system. According to the procedures proposed in previous studies, the power due to the muscle and interaction moments acting on the kicking lower leg was computed. The forward swing of the lower leg during the final phase of kicking was dominated by the power of the interaction moment rather than by that of the muscle moment. The support leg motion contributed to produce more than 50 % of the total amount of positive work due to the power of the interaction moment. The present study proposed a reasonable mechanism for the acceleration of the lower leg swing when its angular velocity exceeds the inherent force-velocity limitation of muscles.

KEY WORDS: Motion-dependent interaction moment, Power, Work

INTRODUCTION: Among many types of kicking in soccer, one of the most common techniques when a fast shot is required is the instep kick. Lees and Nolan (1998), in their review paper, reported that in most of the previous studies, large positive correlations exist between the kicking leg foot velocity just before ball impact and the resultant initial ball velocity. Thus, it is logical to assume that a higher swing velocity of the lower leg of the kicking leg is an essential factor to achieve higher ball velocity.

A large number of investigators have attempted to describe the mechanics underlying accelerating the lower leg swing in kicking. Putnam (1991), although using punt kicking, first revealed the action of motion-dependent interaction moment (interaction moment: the moment generated by acceleration of the adjacent segment) acting on the kicking leg. Putnam (1991) reported that the interaction moment provides a substantial contribution to proximal-distal segment sequences to accelerate the lower leg forward swing. Dörge, Andersen, Sørensen, and Simonsen (2002) applied the same procedure to the soccer instep kick and showed that an increased amount of work due to the interaction moment led to a faster lower leg swing on the preferred kick leg. Nunome, Ikegami, Kozakai, Apriantono, and Sano (2006) exhibited the time-series change of the interaction moment and of the knee joint muscle moment acting on the kicking leg simultaneously. They concluded that the interaction moment due to the knee joint reaction force dominated the acceleration of the lower leg immediately before ball impact. Further, Nunome and Ikegami (2005) demonstrated that a linear upward acceleration of the hip joint on the kicking leg side may induce an effective action of the interaction moment which positively accelerates the lower leg swing velocity. They speculated that the linear upward acceleration was most likely produced by some actions of the support leg. To date, however, there is no study which directly clarified of how support leg motions contribute to the lower leg acceleration of the kicking leg. Therefore, the purpose of the present study was to clarify the contribution of the support leg motion to accelerate the lower leg swing of the kicking leg during the soccer instep kick.

METHODS: Twelve experienced male soccer players (age: 20.9±0.5 years, height: 170.8±5.3 cm, body mass: 69.0±7.3 kg, soccer experience: 14.6±1.3 years with a minimum of 12 years; Mean±SD) from a regional top collegiate league team, volunteered to participate in this study. The experimental protocol was approved by the Human Research Committee of Nagoya University. Informed written consent was obtained from each participant.

Kicking motions were captured by a 10-camera motion capture system (Vicon Nexus) at 500 Hz. Twenty one passive reflective markers were fixed firmly onto body landmarks. Prior to data collection, all participants appropriately warmed-up and performed familiarisation trials. Participants were then instructed to perform maximum effort instep kicks of a stationary ball toward the centre of an indoor soccer goal using their preferred leg (all participants preferred their right leg in the present study). They performed 10 consecutive trials so that two successful shots for each participant (having a good foot-ball impact and getting the centre region of the goal) could be selected for further analysis.

In order to kinetically extract the effect of the support leg on the lower kicking leg (shank and foot), we extended the procedure of Putnam (1991) by adding one more segment, the pelvis, linking the kicking leg to the support leg. Thus, a three-link kinetic chain model composed of pelvis, thigh and lower leg of the swing leg was defined, while the previous studies used a two-link kinetic chain model only consisting of thigh and lower leg. According to the Newton-Euler equation of motion, the following equations [1] and [2] related to the lower leg segment angular and linear motions were obtained.

$$\mathrm{m_l}\mathbf{a_l} = \mathbf{F_p} + \mathrm{m_l}\mathbf{g} \quad [1]$$
$$\mathrm{I_l}\dot{\boldsymbol{\omega}}_\mathbf{l} = \mathbf{T_k} + \mathbf{r_p} \times \mathbf{F_p} \quad [2]$$

For these equations, $\mathrm{m_l}$ is the mass of the lower leg, $\mathbf{a_l}$ is the acceleration of the lower leg centre of mass, $\mathbf{F_p}$ is the joint reaction force acting the distal end of the lower leg, $\mathbf{g}$ is gravity (-9.81 m/s^2), $\mathrm{I_l}$ is the moment of inertia, $\dot{\boldsymbol{\omega}}_\mathbf{l}$ is the segmental angular acceleration of the lower leg, $\mathbf{r_p}$ is the vector from the lower leg centre of mass to the knee joint centre (moment

$$\mathbf{a_l} = (\mathbf{a_l} - \mathbf{a_{hs}}) + \mathbf{a_{hs}} \quad [3]$$

arm), and $\mathbf{T_k}$ is the knee joint muscle moment. Equation [2] shows that net moment of the lower leg ($\mathrm{I_l}\dot{\boldsymbol{\omega}}_\mathbf{l}$) can be divided into two components: Knee joint muscle moment ($\mathbf{T_k}$) and interaction moment ($\mathbf{r_p} \times \mathbf{F_p}$) due to the joint reaction force. Using relative linear acceleration between each joint, $\mathbf{a_l}$ can be expressed as follows:

where $\mathbf{a_{hs}}$ is the acceleration of the hip joint centre of the support leg. Therefore $\mathbf{a_l} - \mathbf{a_{hs}}$ is the relative acceleration of the lower leg centre of mass to that of the hip joint centre of the support leg. By substituting the equations [1] and [3] into [2], the net moment ($\mathrm{I_l}\dot{\boldsymbol{\omega}}_\mathbf{l}$) can be expressed as the following equation [4].

$$\mathrm{I_l}\dot{\boldsymbol{\omega}}_\mathbf{l} = \mathbf{T_k} + \mathbf{r_p} \times \mathrm{m_l}(\mathbf{a_h} - \mathbf{a_{hs}} - \mathbf{g}) + \mathbf{r_p} \times \mathrm{m_l}\mathbf{a_{hs}} \quad [4]$$

In this equation, second and third terms exhibit the interaction moment due to swing leg motion (including pelvis motion) and the one due to support leg motion, respectively. We multiplied each term of equation [2] and [4] by the lower leg swing velocity ($\boldsymbol{\omega}_\mathbf{l}$), the powers generated by each term were computed as the following equation [5] or [6].

$$\mathrm{I_l}\dot{\boldsymbol{\omega}}_\mathbf{l}\boldsymbol{\omega}_\mathbf{l} = \mathbf{T_k}\boldsymbol{\omega}_\mathbf{l} + \mathbf{r_p} \times \mathbf{F_p}\boldsymbol{\omega}_\mathbf{l} \quad [5]$$
$$= \mathbf{T_k}\boldsymbol{\omega}_\mathbf{l} + \mathbf{r_p} \times \mathrm{m_l}(\mathbf{a_h} - \mathbf{a_{hs}} - \mathbf{g})\boldsymbol{\omega}_\mathbf{l} + \mathbf{r_p} \times \mathrm{m_l}\mathbf{a_{hs}}\boldsymbol{\omega}_\mathbf{l} \quad [6]$$

These powers were separated into the component about the axis perpendicular to the thigh-shank plane of the swing leg.

All time-series data were smoothed using a fourth-order Butterworth low-pass filter with a cut-off frequency of 25 Hz after ball impact artifacts were removed (Nunome et al., 2006). The period from the touch-down of the support leg to ball impact was normalized to 100 %. To illustrate the data before the touch-down, the analyzed portion was expanded to -50 % using the same scaling factor for this normalization.

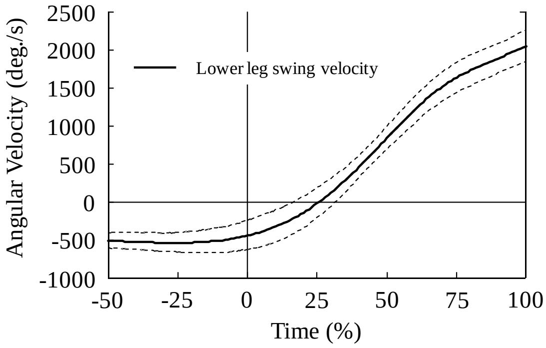

Figure 1. The average value (±SD) of the lower leg swing angular velocity: forward (+) / back (-) swing.

RESULTS: The average value (±SD) of the lower leg swing velocity ($\boldsymbol{\omega}_\mathbf{l}$) of the kicking leg is shown in Figure 1. Shortly after the touch-down of the support leg, the lower leg initiated its forward swing motion. The forward swing angular velocity eventually reached its peak value (2051±205 degree/s) at ball impact.

Figure 2 shows the average values (±SD) of the power due to the knee joint muscle moment ($\mathbf{T}_\mathbf{k}\boldsymbol{\omega}_\mathbf{l}$) and due to the interaction moment ($\mathbf{r}_\mathbf{p} \times \mathbf{F}_\mathbf{p}\boldsymbol{\omega}_\mathbf{l}$). An appreciable positive power due to the muscle moment began to be generated after 25 % of the time and its onset coincided with the lower leg forward swing (see Figure 1). At this time, the power due to the interaction moment was small and thus negligible. In the final phase of kicking (after 50 % of the time), the positive power due to the muscle moment reduced considerably and came to yield a large negative power from 75 % of the time until ball impact. In contrast, the power due to the interaction moment rapidly increased to a large positive value starting at 75 % of the time, reaching its peak value at ball impact.

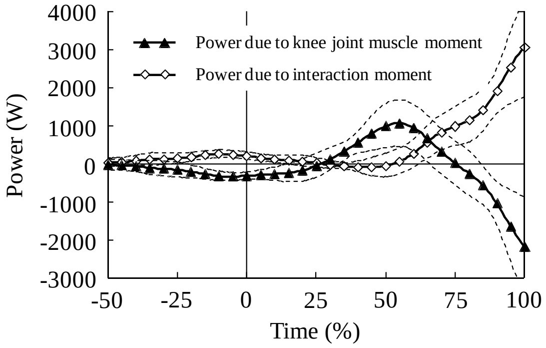

Figure 2. The average value (±SD) of the knee joint muscle moment power and the interaction moment power: forward (+) / back (-) swing.

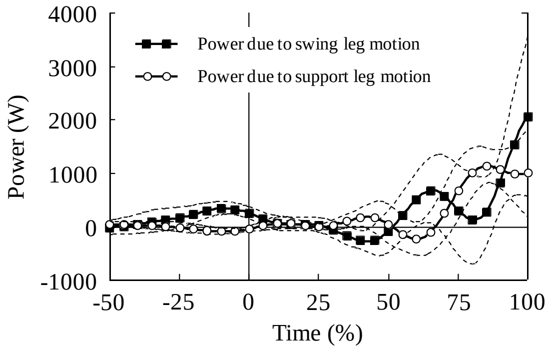

Figure 3. The average value (±SD) of the separated powers of the interaction moment: that due to the kicking leg motion and that due to the support leg motion: forward (+) / back (-) swing.

In Figure 3, the average power (±SD) due to the interaction moment was separated into two components: the power due to the swing leg motion ($\mathbf{r}_\mathbf{p} \times \mathrm{m}_\mathrm{l}(\mathbf{a}_\mathbf{h} - \mathbf{a}_\mathbf{hs} - \mathbf{g})\boldsymbol{\omega}_\mathbf{l}$) and that due to the support leg motion ($\mathbf{r}_\mathbf{p} \times \mathrm{m}_\mathrm{l}\mathbf{a}_\mathbf{hs}\boldsymbol{\omega}_\mathbf{l}$). For both power sources, increases of positive power were consistently observed during the final phase of kicking.

DISCUSSION: In the present study, we focused on soccer kicking dynamics and tried to extract the contribution of the support leg motion on the lower kicking leg forward swing through a modified procedure of Putnam (1991).

The previous studies (Putnam, 1991; Dörge et al., 2002) reported that the interaction moment was an important factor for accelerating the lower leg swing of the kicking leg. Nunome et al. (2006) also indicated the importance of the interaction moment, and demonstrated that this moment was more dominant in accelerating the lower leg swing than the knee joint muscle moment, when looking at its action immediately before ball impact. Thus, we compared the powers due to these two different types of moments and found a similar result to that of the previous studies.

As mentioned above, the acceleration of the lower kicking leg is most likely attributed to the power due to interaction moment during the final phase of kicking. Thus, an attempt was made to divide the power due to interaction moment into two components: that due to the kicking leg motion and that due to the support leg motion. The present study succeeded in clearly demonstrating the detailed simultaneous power profiles of both interaction moments due to the kicking leg motion and to the support leg motion, respectively. Large positive values were observed for both of the power components (Figure 3). In order to quantitatively determine the proportion of the support leg contribution to the total power production, the gross amounts of the work due to these two moments were additionally calculated by integrating the powers during the forward swing (the period exhibited a positive angular velocity of the lower leg, see Figure 1). The amount of the work due to the support leg motion yielded 56.4±22.8 % of the total amount of the work due to the interaction moment (sum of the work due to the swing and the support leg motion). This result suggests that the acceleration present at the hip joint centre on the support leg ($\mathbf{a_{hs}}$) has a significant role in producing the positive power due to the interaction moment, which contributed to accelerate the lower leg swing during the final phase of kicking.

Furthermore, to identify which aspect of the support leg motion mainly contributed to the swing leg acceleration, the acceleration generated at the hip joint centre of the support leg ($\mathbf{a_{hs}}$) was decomposed into three components: X (medio-lateral), Y (antero-posterior) and Z (vertical) according to the global orthogonal reference frame. The power and the amount of work due to the each component were computed using the procedure of Nunome and Ikegami (2005). The amount of work due to Z component (upward) yielded the major portion (78.2±20.4 %). Inoue, Nunome, Sterzing, Shinkai and Ikegami (2012) analyzed support leg joint kinetics and reported that the positive power due to the knee extension moment was seen at the support leg just before ball impact. Thus, it may be interpreted that the power due to the knee joint moment of the support leg most likely serves to lift the body upward and thereby contributes to the acceleration of the lower leg swing of the kicking leg.

From the perspective of muscle physiology, Nunome et al. (2006) speculated that, as the angular velocity of the kicking lower leg immediately before ball impact most likely exceeds the inherent force-velocity limitation of muscles, the muscular system related to the lower leg motion became incapable of generating any further concentric force. That means that the knee extensors of the kicking leg have no chance to dominate the lower leg swing during the final phase of kicking where the lower leg swing velocity reaches approximately 2000 degree/s. On the other hand, as the knee extensors of the support leg do not face such a high velocity condition, there still remains a large capacity to produce a positive power during the final phase of kicking. From our results, it can be proposed as a reasonable mechanical principle of how to accelerate the lower leg swing of the kicking leg immediately before ball impact.

CONCLUSION: It can be concluded that the support leg motion generated a large positive power due to the interaction moment acting on the lower leg of the kicking leg, thereby having a significant effect on the acceleration of the kicking leg swing immediately before ball impact.

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